# EXHIBIT IV

US010274266B2

(12) **United States Patent**
**Lyon**

(10) **Patent No.: US 10,274,266 B2**
(45) **Date of Patent: Apr. 30, 2019**

(54) **FLUID HEAT EXCHANGE SYTEMS**

(71) Applicant: **CoolIT Systems Inc.**, Calgary (CA)

(72) Inventor: **Geoff Sean Lyon**, Calgary (CA)

(73) Assignee: **CoolIT Systems, Inc**, Calgary (CA)

( * ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **15/912,478**

(22) Filed: **Mar. 5, 2018**

(65) **Prior Publication Data**

US 2018/0195810 A1 Jul. 12, 2018

**Related U.S. Application Data**

(63) Continuation of application No. 15/263,210, filed on Sep. 12, 2016, now Pat. No. 9,909,820, which is a (Continued)

(51) **Int. Cl.**
***F28F 7/00*** (2006.01)
***F28F 3/12*** (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ............... ***F28F 3/12*** (2013.01); ***F28D 15/00*** (2013.01); ***F28F 3/048*** (2013.01); ***H01L 23/473*** (2013.01); *H01L 2924/0002* (2013.01)

(58) **Field of Classification Search**
CPC .. F28F 3/12; F28F 3/048; F28D 15/00; H01L 23/473; H01L 2924/0002
(Continued)

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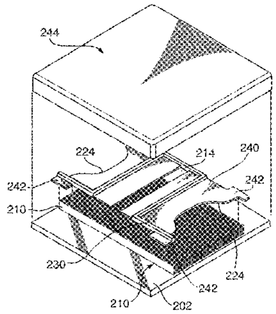
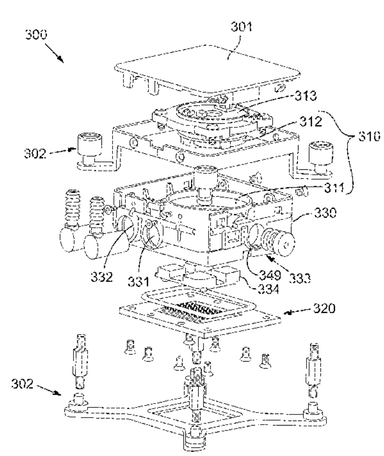
*Primary Examiner* — Claire E Rojohn, III
(74) *Attorney, Agent, or Firm* — Ganz Pollard, LLC

(57) **ABSTRACT**

A fluid heat exchanger includes: a heat spreader plate including an intended heat generating component contact region; a plurality of microchannels for directing heat transfer fluid over the heat spreader plate, the plurality of microchannels each having a first end and an opposite end and each of the plurality of microchannels extending substantially parallel with each other microchannel and each of the plurality of microchannels having a continuous channel flow path between their first end and their opposite end; a fluid inlet opening for the plurality of microchannels and positioned between the microchannel first and opposite ends, a first fluid outlet opening from the plurality of microchannels at each of the microchannel first ends; and an opposite fluid outlet opening from the plurality of microchannels at each of the microchannel opposite ends, the fluid inlet opening and the first and opposite fluid outlet openings providing that any flow of heat transfer fluid that passes into the plurality of microchannels, flows along the full length of each of the plurality of microchannels in two directions outwardly from the fluid inlet opening. A method of cooling a heat generating component uses a fluid heat exchanger that splits a mass flow of coolant.

**21 Claims, 12 Drawing Sheets**



**Related U.S. Application Data**

continuation of application No. 13/401,618, filed on Feb. 21, 2012, now Pat. No. 9,453,691, which is a continuation-in-part of application No. 12/189,476, filed on Aug. 11, 2008, now Pat. No. 8,746,330.

(60) Provisional application No. 61/512,379, filed on Jul. 27, 2011, provisional application No. 60/954,987, filed on Aug. 9, 2007.

(51) **Int. Cl.**
***F28D 15/00*** (2006.01)
***H01L 23/473*** (2006.01)
***F28F 3/04*** (2006.01)

(58) **Field of Classification Search**
USPC ................ 165/80.4, 104.28, 104.31, 104.33
See application file for complete search history.

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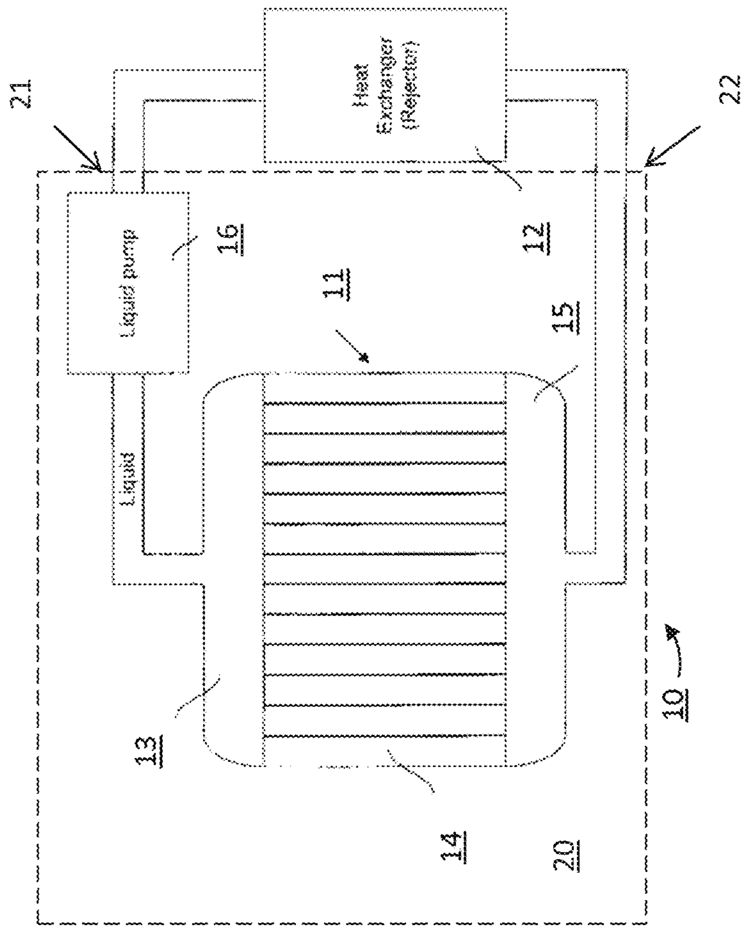
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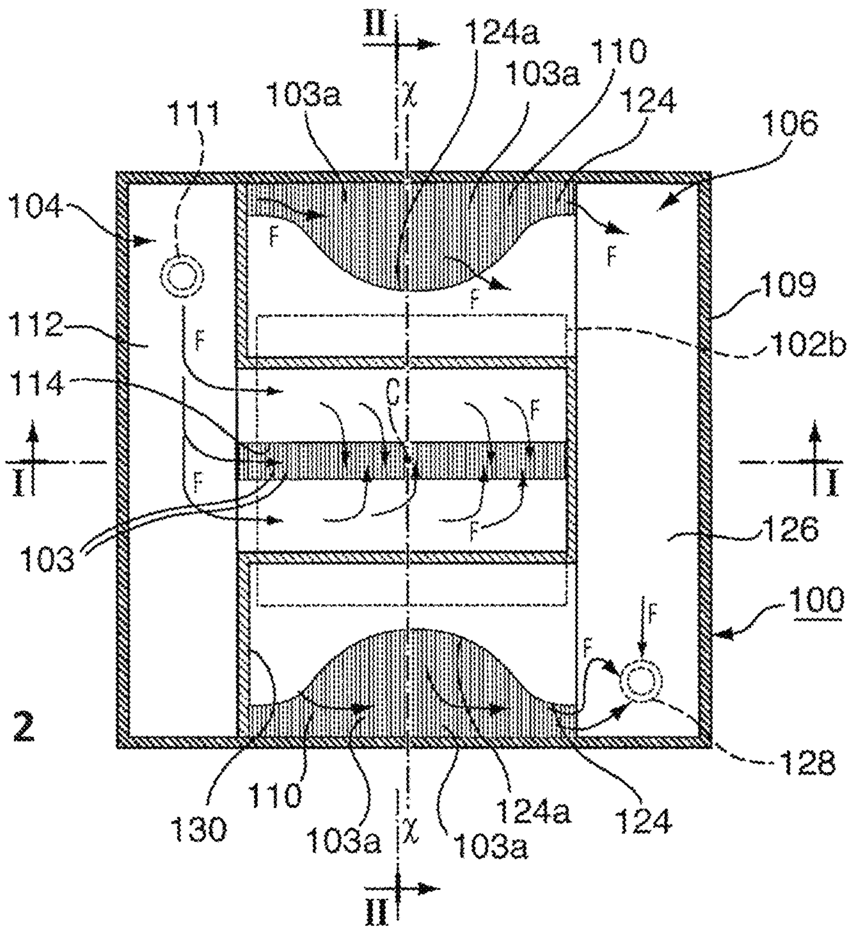
FIG. 1

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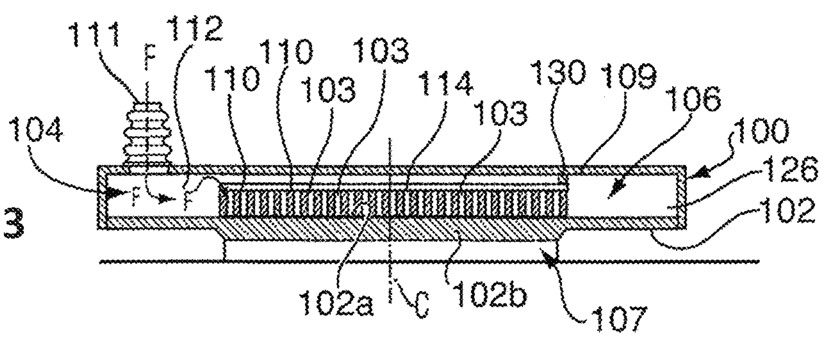


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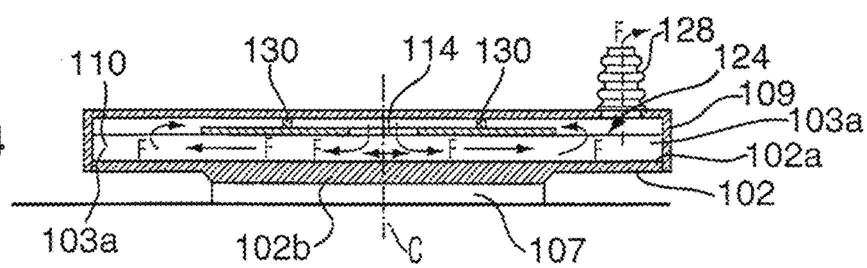


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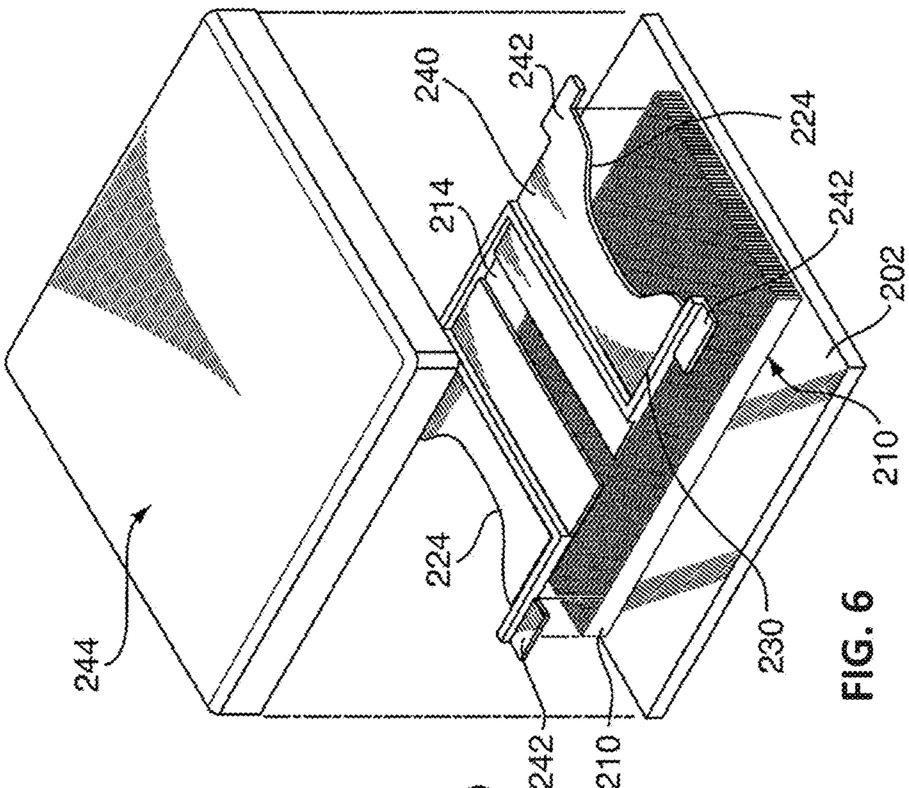
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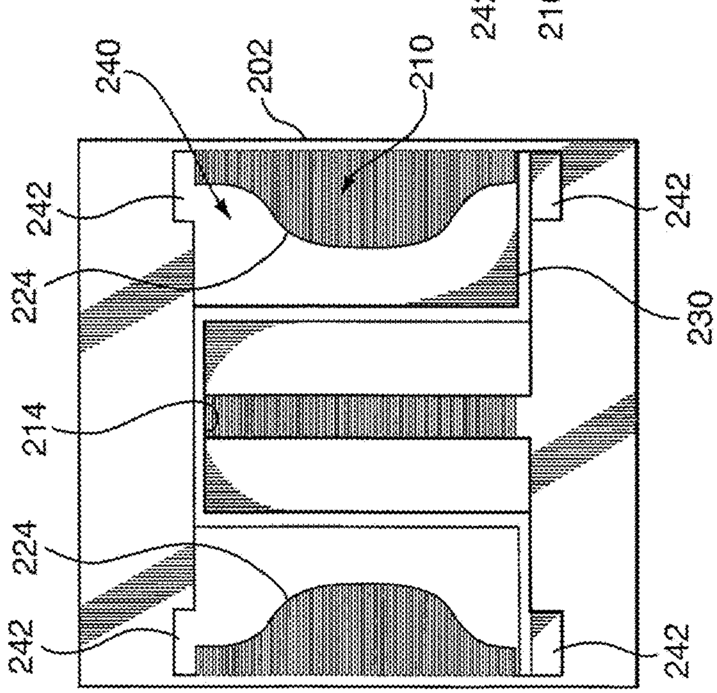
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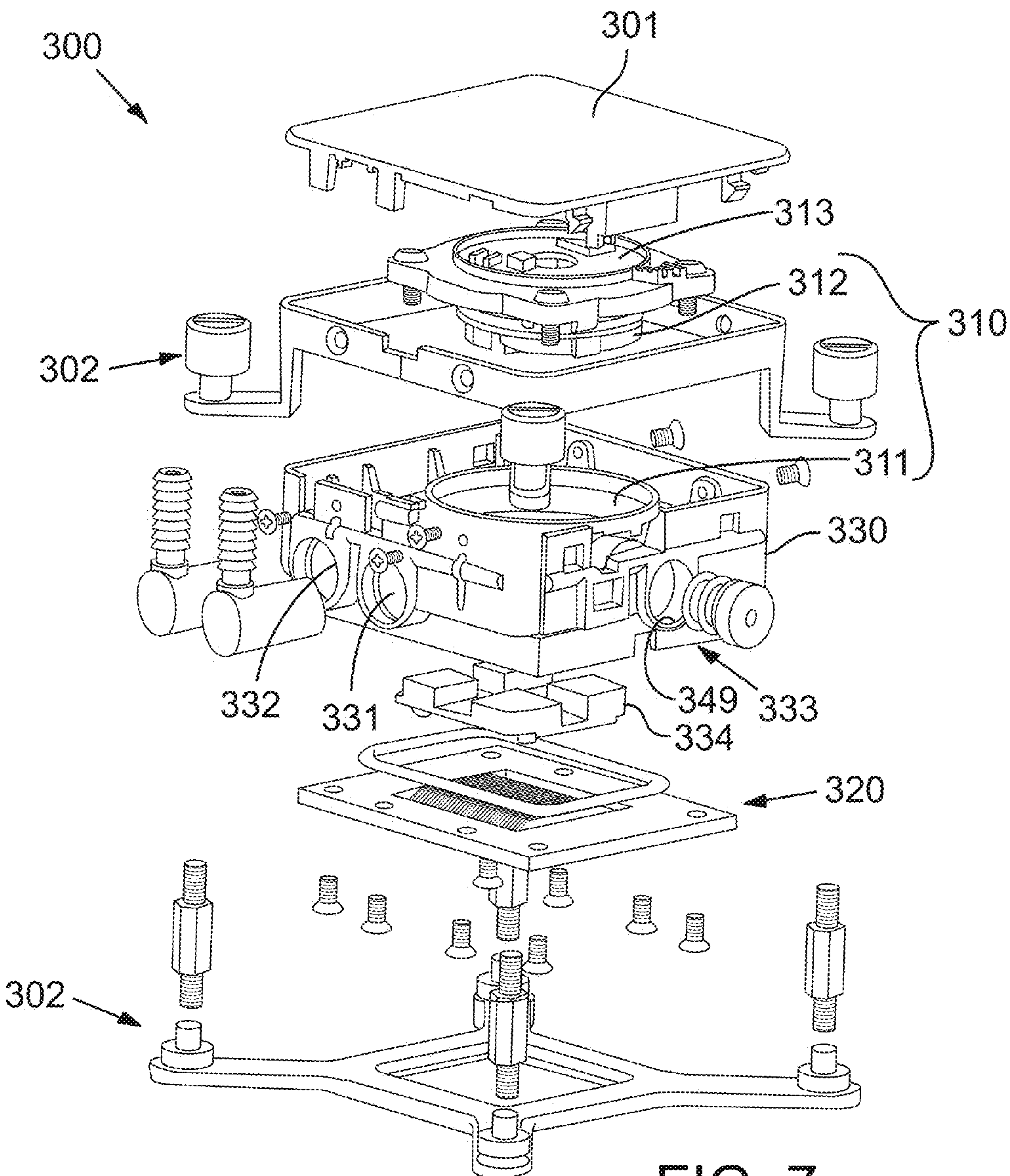


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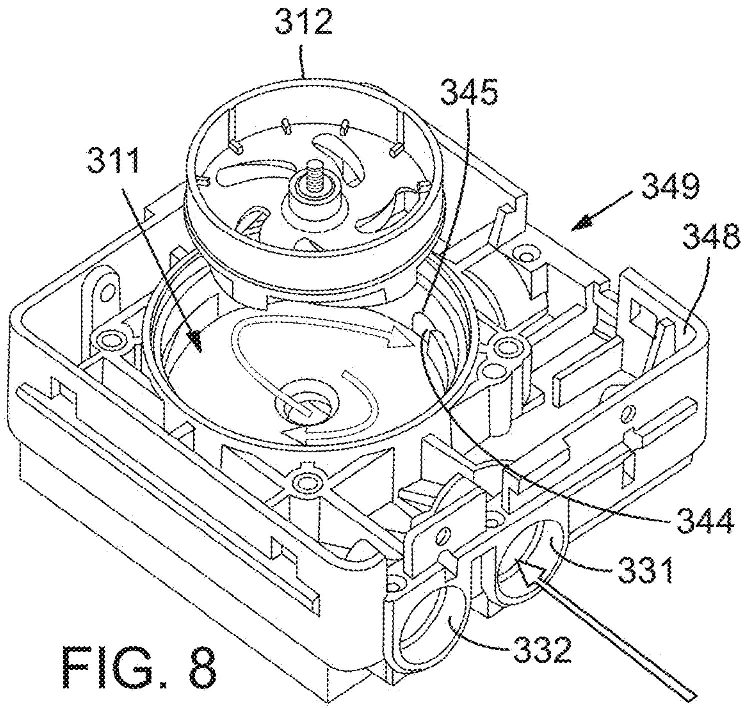
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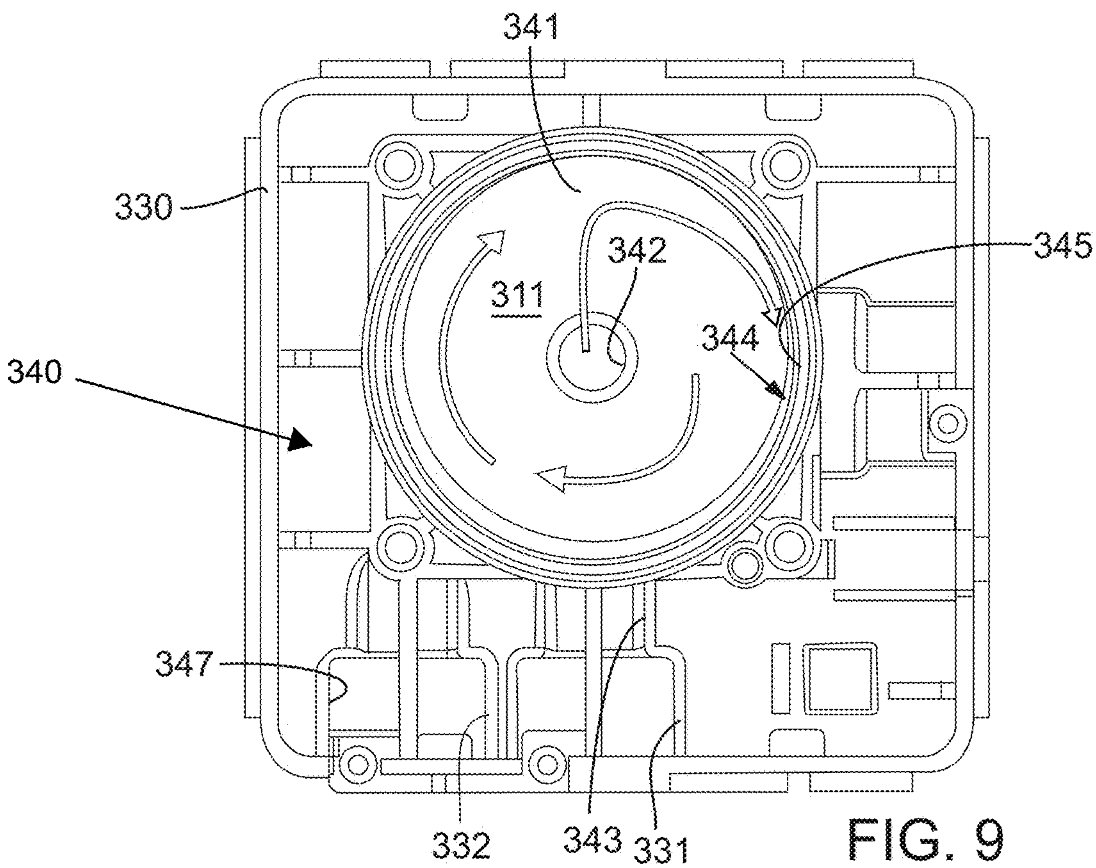
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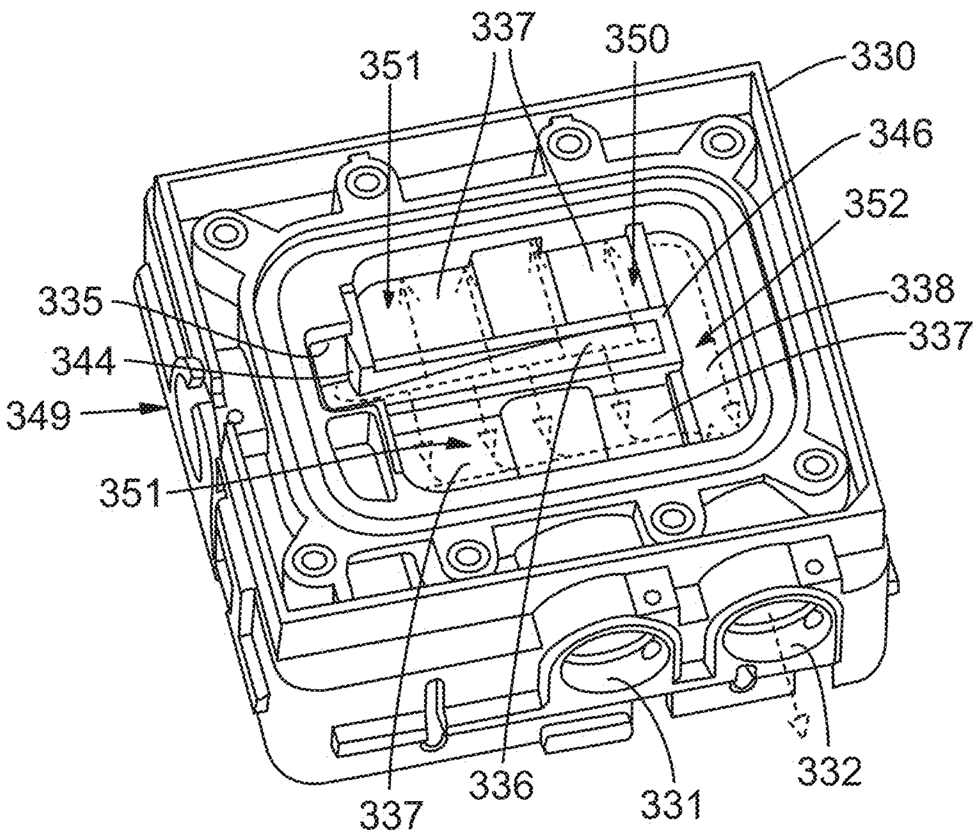


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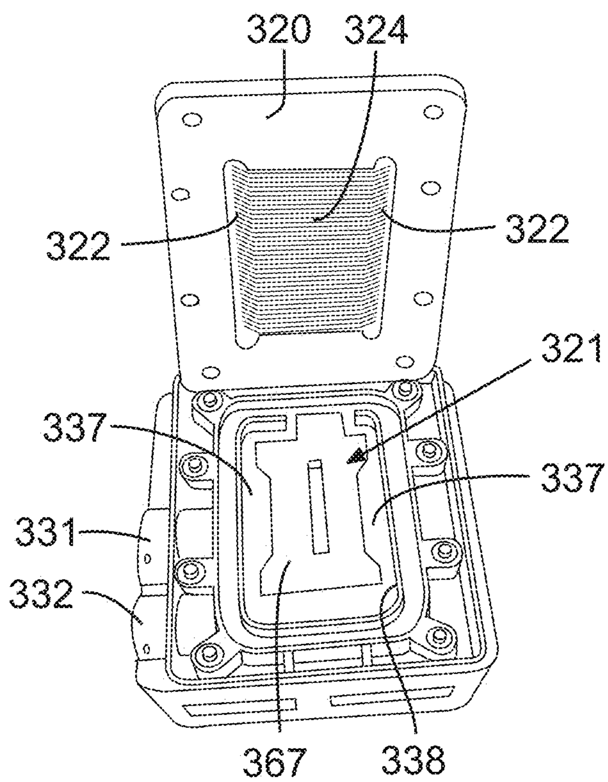
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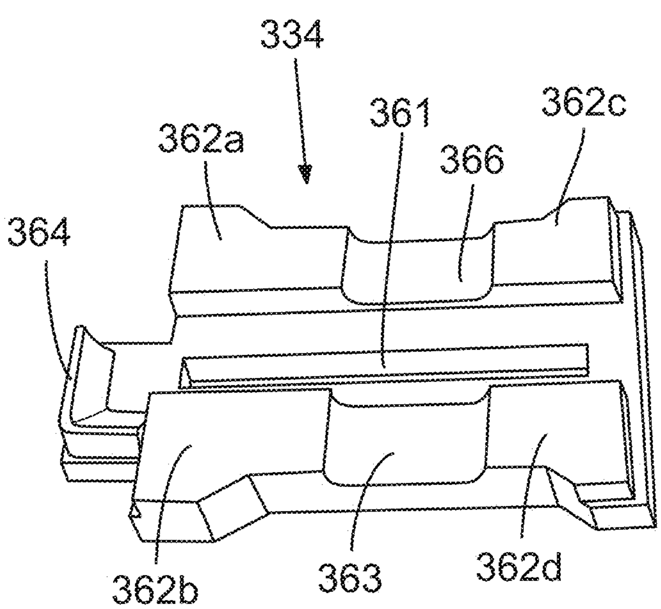
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FIG. 12

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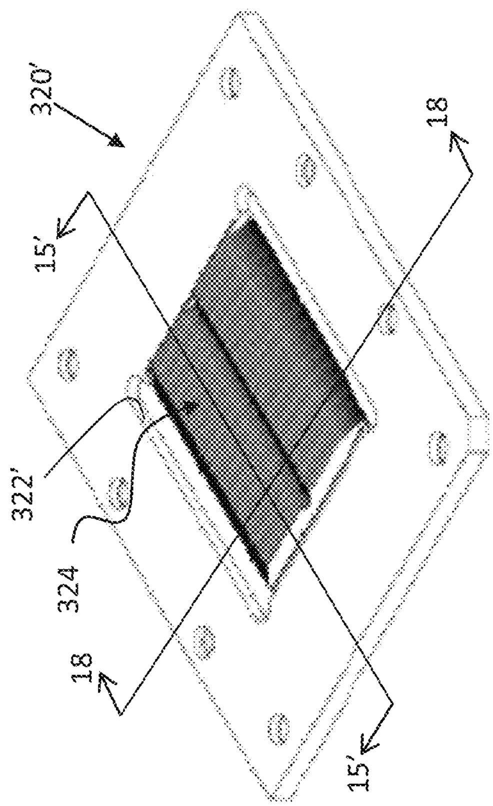
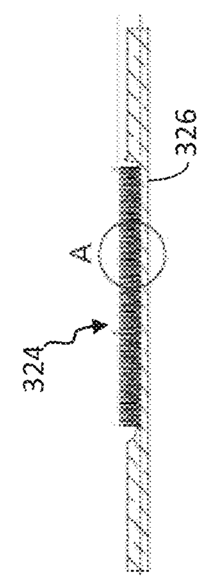



FIG. 14

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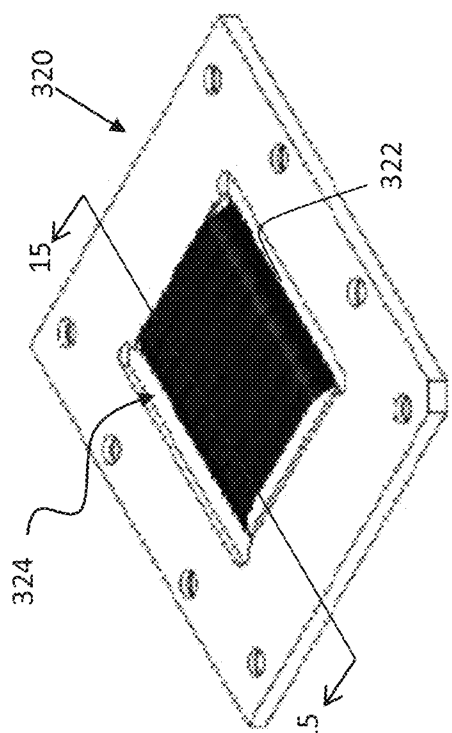



FIG. 13

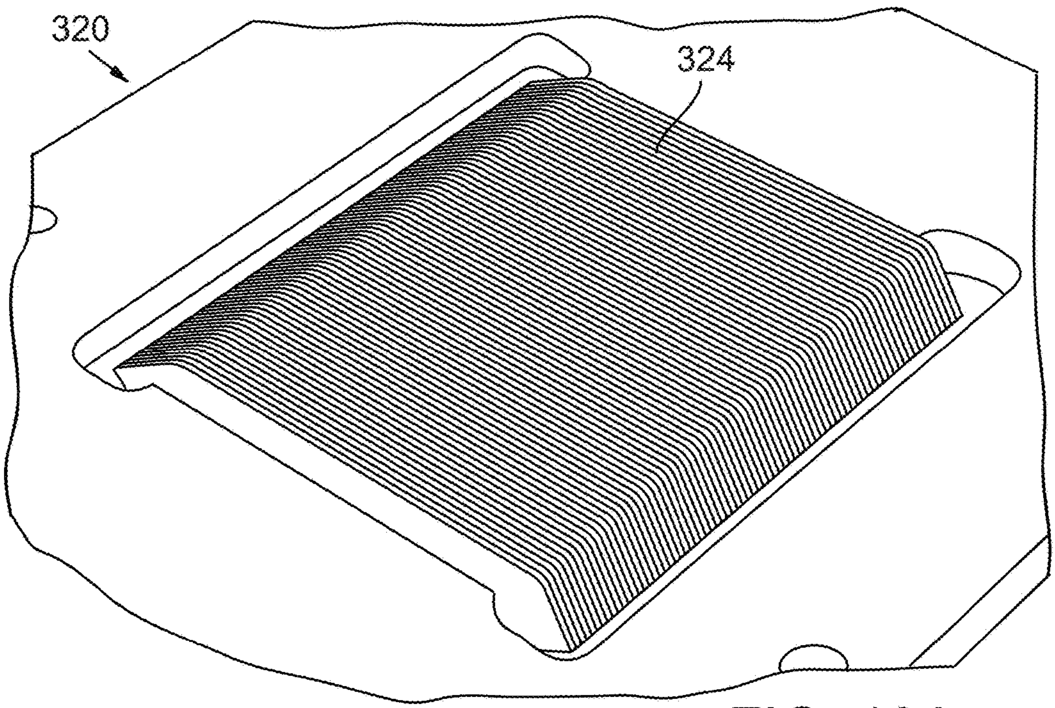



FIG. 13A

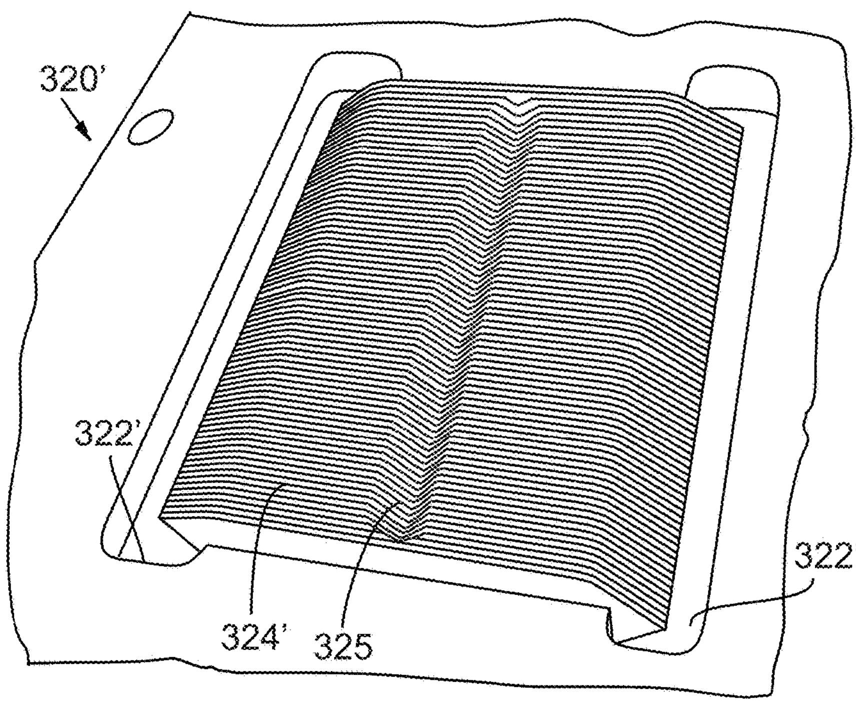



FIG. 14A

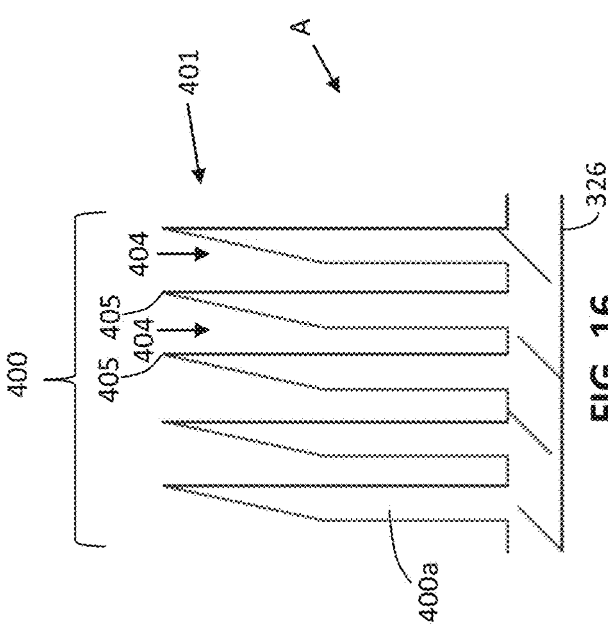
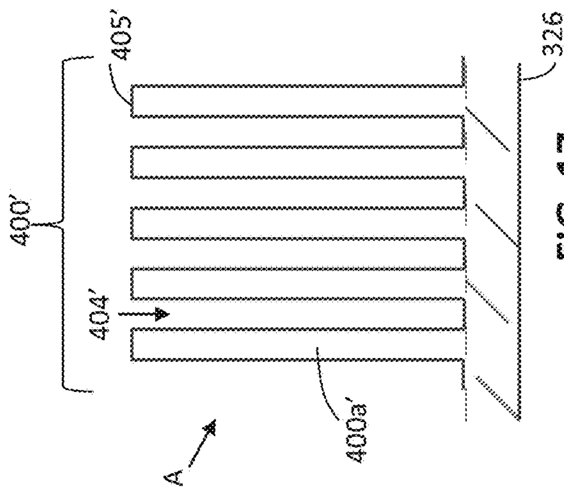



FIG. 16

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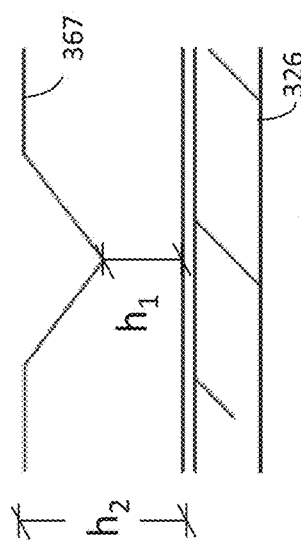


FIG. 18A

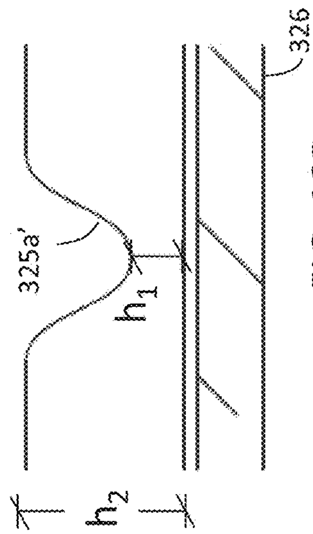


FIG. 18B

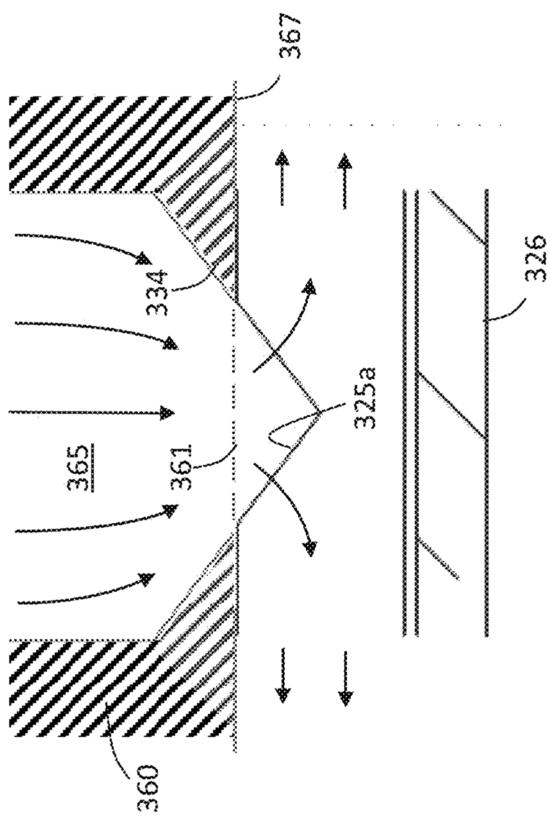


FIG. 19

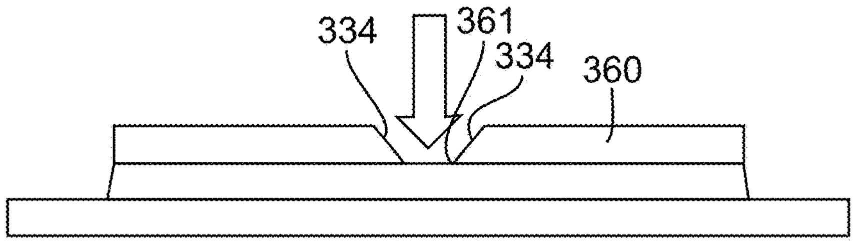


FIG. 19A

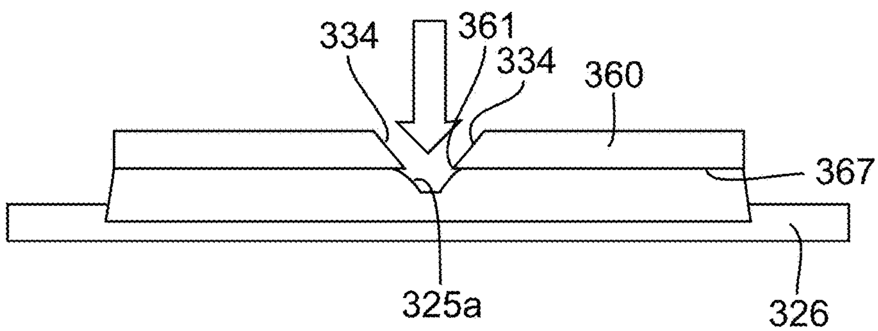


FIG. 19B

**FLUID HEAT EXCHANGE SYTEMS**

## RELATED APPLICATIONS

This application claims the benefit of and priority to U.S. patent application Ser. No. 15/263,210, filed on Sep. 12, 2016, which is a continuation of U.S. patent application Ser. No. 13/401,618, filed on Feb. 21, 2012, which claims benefit of and priority to U.S. Provisional Patent Application No. 61/512,379, filed on Jul. 27, 2011, and is a continuation-in-part of U.S. patent application Ser. No. 12/189,476, filed on Aug. 11, 2008, which claims benefit of and priority to U.S. Provisional Patent Application No. 60/954,987, filed on Aug. 9, 2007, and which applications are hereby incorporated by reference in their respective entireties, for all purposes.

## BACKGROUND

The innovations and related subject matter disclosed herein (collectively referred to as the "disclosure") generally pertain to fluid heat exchange systems. Some systems are described in relation to electronics cooling applications by way of example, though the disclosed innovations may be used in a variety of other applications.

Fluid heat exchangers are used to cool electronic and other devices by accepting and dissipating thermal energy therefrom.

Fluid heat exchangers seek to dissipate to a fluid passing there through, thermal energy communicated to them from a heat source.

Despite the existence of many previously proposed fluid heat exchange systems, there remains a need for heat exchange systems configured to provide improved thermal performance. As well, there remains a need for systems configured for existing and developing small form factors, and more particularly. For example, there remains a need for low-profile heat exchange assemblies (e.g., integrated heat sink and pump assemblies) having a vertical component height of about 27 mm, such as between about 24 mm to about 27.5 mm, or less. There also remains a need for integrated components and systems having fewer fluid connections. In addition, there is a need for low-pressure-loss flow transitions in integrated heat exchange components.

## SUMMARY

The innovations disclosed herein overcome many problems in the prior art and address the aforementioned, as well as other, needs. The innovations disclosed herein pertain generally to fluid heat exchange systems and more particularly, but not exclusively, to approaches for integrating components in such systems. For example, some innovations are directed to low-profile pump housings. Other innovations are directed to heat sink designs that deliver improved heat-transfer and/or pressure-loss performance. And other innovations are directed to approaches for eliminating system components while retaining their respective functions.

In accordance with a broad aspect of the innovations disclosed herein, there is provided a fluid heat exchanger comprising: a heat spreader plate including an intended heat generating component contact region; a plurality of microchannels for directing heat transfer fluid over the heat spreader plate, the plurality of microchannels each having a first end and an opposite end and each of the plurality of microchannels extending substantially parallel with each



other microchannel and each of the plurality of microchannels having a continuous channel flow path between their first end and their opposite end; a fluid inlet opening for the plurality of microchannels and positioned between the microchannel first and opposite ends, a first fluid outlet opening from the plurality of microchannels at each of the microchannel first ends; and an opposite fluid outlet opening from the plurality of microchannels at each of the microchannel opposite ends, the fluid inlet opening and the first and opposite fluid outlet openings providing that any flow of heat transfer fluid that passes into the plurality of microchannels, flows along the full length of each of the plurality of microchannels in two directions outwardly from the fluid inlet opening.

In accordance with another broad aspect of the disclosed innovations, there is provided a method for cooling a heat generating component comprising: providing a fluid heat exchanger including a heat spreader plate; a plurality of microchannels for directing heat transfer fluid over the heat spreader plate, the plurality of microchannels each having a first end and an opposite end and each of the plurality of microchannels having a continuous channel flow path between their first ends and their opposite ends; a fluid inlet opening for the plurality of microchannels and positioned between the microchannel first and opposite ends, a first fluid outlet opening from the plurality of microchannels at each of the microchannel first ends; and an opposite fluid outlet opening from the plurality of microchannels at each of the microchannel opposite ends; mounting the heat spreader plate onto the heat generating component creating a heat generating component contact region where the heat generating component contacts the heat spreader plate; introducing a flow of heat exchanging fluid to the fluid heat exchanger; urging the flow of heat exchanging fluid through the fluid inlet into the plurality of microchannels first to a microchannel region between the ends of the microchannel; and, diverting the flow of heat exchanging fluid into a plurality of subflows that each flow away from the other, a first of the plurality of subflows flowing from the fluid inlet toward the first fluid outlet and a second of the plurality of subflows flowing from the fluid inlet toward the opposite fluid outlet.

According to another broad aspect of the disclosed innovations, heat exchange systems are disclosed.

Some described heat exchange systems have a heat sink with a plurality of juxtaposed fins defining a corresponding plurality of microchannels between adjacent fins, and a recessed groove extending transversely relative to the fins. A manifold body at least partially defines an opening generally overlying the groove.

The manifold body and the groove can together define a portion of an inlet manifold. The inlet manifold can be configured to hydraulically couple in parallel each of the microchannels to at least one other of the microchannels.

The heat sink can have a heat spreader, with each of the fins extending from the heat spreader. The fins and the heat spreader can form a unitary construction, in some heat sink embodiments. Each of the fins can define a corresponding distal edge spaced from the heat spreader, and the groove can be recessed from the respective plurality of distal edges. In some heat sink embodiments, a lowermost extent of the recessed groove is spaced from the heat spreader. In other heat sink embodiments, a lowermost extent of the recessed groove is substantially coextensive with the heat spreader. As described below, each of the respective distal edges can define a corresponding recessed portion, thereby defining the recessed groove.

In some embodiments, the recessed groove comprises a first groove positioned adjacent a first end of the fins and a second groove positioned adjacent a second, opposing end of the fins. For example, the first groove and the second groove can define respective portions of an exhaust manifold.

The cross-sectional profile of the recessed groove can have any of a variety of shapes. For example, in some heat sink embodiments, a cross-sectional profile of the recessed groove comprises a selected one or more of the group consisting of a v-shaped notch, a semi-circle, a parabola, a hyperbola, and a notch having at least one substantially straight edge.

In some heat sink embodiments, a ratio of a representative height of the plurality of fins to a representative depth of the groove is between about 10:1 and about 10:7. For example, the ratio of the representative height to the representative depth can be between about 3:1 and about 2:1.

The opening in the manifold body can have a recessed region and an aperture extending through the manifold body from the recessed region. In some instances, the recessed region in the manifold body is a tapered recessed region having at least one cross-sectional dimension that diminishes with increasing depth of the recessed region. A slope of the recessed groove adjacent the manifold body can be substantially continuous with a slope of the recessed region in the manifold body adjacent the groove. The recessed region, the aperture and the groove can together define a flow transition having a characteristic length scale between about 150% and about 200% greater than a corresponding characteristic length scale of the aperture.

In some heat exchange systems of the type described herein, the inlet manifold can be configured to deliver a flow of a fluid to each of the microchannels in a transverse direction relative to a longitudinal axis of the respective microchannels. Some heat exchange systems have q body defining an inlet plenum. The inlet plenum and the inlet manifold can together be configured to deliver a fluid flow to in a direction generally transverse to the fins. For example, the inlet manifold can be configured to deliver an impingement flow of the fluid to each of the microchannels.

In some heat sink embodiments, each of the fins in the plurality of fins defines a corresponding beveled distal edge.

Some heat exchange systems also have a unitary body defining a first side and a second side positioned opposite the first side. A portion of the inlet plenum and a portion of the inlet manifold can be respectively recessed from the first side. A recess from the second side can define a pump volute, and the portion of the inlet plenum recessed from the first side can be positioned adjacent the pump volute. The recess defining the pump volute can be a substantially cylindrically-shaped recess having a longitudinal axis extending substantially perpendicularly to the second side. The unitary body can define an opening extending generally tangentially of the cylindrically-shaped recess and hydraulically couple the pump volute to the inlet plenum.

The body can define a second recessed region adjacent the inlet manifold recess and a wall separating the second recessed region from the inlet manifold recess. The manifold body can be configured to straddle the inlet manifold recess and matingly engage the body such that the manifold body so occupies a portion of the second recessed region as to define an exhaust manifold that generally overlies a respective portion of each of the microchannels. The respective portions of the plurality of microchannels can be spaced from the inlet manifold.



In accordance with yet another broad aspect of the disclosed innovations, some described heat exchange systems have a heat sink with a plurality of juxtaposed fins defining a corresponding plurality of microchannels between adjacent fins. Each of the fins can define a respective beveled distal edge. A manifold body can overlie at least a portion of each of the beveled distal edges and define an opening configured to deliver a flow of fluid to the microchannels in a direction transverse to the microchannels.

A distance between a respective beveled distal edge and the heat spreader can define a height of the respective fin. Each respective fin can define a first end and a second end, and extend longitudinally in a spanwise direction relative to the heat spreader between the first and the second end. The respective fin height of one or more of the plurality of fins can vary along the spanwise direction. The manifold body can have a compliant portion urging against at least a portion of each of the distal edges. For example, the variation in fin height along the spanwise direction can define a non-linear contour of the respective distal edge, and the compliant portion of the manifold body can generally conform to the non-linear contour.

A recessed groove can extend transversely relative to the fins and the opening can generally overlie the groove. Each of the respective distal edges can define a corresponding recessed portion, thereby defining the recessed groove.

A ratio of a representative height of the plurality of fins to a representative depth of the groove can be between about 10:1 and about 10:7. For example, the ratio of the representative height to the representative depth can be between about 3:1 and about 2:1.

According to another broad aspect of the disclosed innovations, unitary constructs are described. For example, a unitary construct can have a first side, a second side positioned opposite the first side, and a substantially continuous perimeter wall extending between the first side and the second side. A floor can generally separate the first side from the second side. The first side can define a substantially cylindrically-shaped recess and the second side can define a recess having a region positioned radially outward of the substantially cylindrically-shaped recess defined by the first side.

In some instances, the unitary construct can define an aperture extending between the substantially cylindrically-shaped recess and the portion of the recess from the second side positioned radially outward of the substantially cylindrically-shaped recess.

The perimeter wall can define one or more perimeter recesses. The construct can define an aperture in the floor extending between one of the perimeter recesses and the substantially cylindrically-shaped recess. The construct can define an aperture extending between one of the perimeter recesses and the recess defined by the second side. The construct can define an aperture extending between one of the perimeter recesses and the portion of the recess from the second side positioned radially outward of the substantially cylindrically-shaped recess.

The one or more perimeter recesses can include a first perimeter recess and a second perimeter recess. The construct can define an aperture extending between the second perimeter recess and the recess defined by the second side. The perimeter wall can also define a third perimeter recess and the construct can define an aperture extending between the third perimeter recess and the portion of the recess from the second side positioned radially outward of the substantially cylindrically-shaped recess.

Some embodiments of the construct generally define a housing. The substantially cylindrically-shaped recess can define a pump volute, and the recess from the second side can define a plenum. The plenum can be a heat sink inlet plenum defined by the portion of the recess from the second side positioned radially outward of the substantially cylindrically-shaped recess. The recess from the second side can define a portion of a heat-sink inlet manifold, a portion of a heat-sink outlet manifold, and a portion of a heat-sink outlet manifold.

It is to be understood that other innovative aspects will become readily apparent to those skilled in the art from the following detailed description, wherein various embodiments are shown and described by way of illustration. As will be realized, other and different embodiments are possible and several details are capable of modification in various other respects, all without departing from the spirit and scope of the principles disclosed herein.

Accordingly the drawings and detailed description are to be regarded as illustrative in nature and not as restrictive.

## BRIEF DESCRIPTION OF THE DRAWINGS

Unless specified otherwise, the accompanying drawings illustrate aspects of the innovative subject matter described herein. Referring to the drawings, wherein like reference numerals indicate similar parts throughout the several views, several aspects of the presently disclosed principles are illustrated by way of example, and not by way of limitation, in detail in the drawings, wherein:

FIG. **1** shows a fluid circuit configured to transfer heat from one region to another with a circulatable working fluid.

FIG. **2** shows a top plan view of a fluid heat exchanger having a top cap cut away to facilitate viewing internal components;

FIG. **3** shows a sectional view along line I-I of FIG. **2**;

FIG. **4** shows a sectional view along line II-II of FIG. **3**;

FIG. **5** shows an exploded, perspective view of another fluid heat exchanger;

FIG. **6** shows a top plan view of the fluid heat exchanger shown in FIG. **5** assembled with its top cap removed;

FIG. **7** illustrates an exploded view of an embodiment of an integrated pump and heat exchanger assembly.

FIG. **8** illustrates an isometric view of an exploded subassembly of the integrated housing and pump impeller shown in FIG. **7**.

FIG. **9** illustrates a partial cross-sectional view from above the integrated housing shown in FIGS. **7** and **8**.

FIG. **10** illustrates an isometric view from below of the integrated housing shown in FIGS. **7**, **8** and **9** with a flow path of a fluid shown as a dashed line.

FIG. **11** illustrates an exploded view of a subassembly comprising the heat sink, the integrated housing and the manifold insert shown in FIG. **7**.

FIG. **12** illustrates an isometric view from above the insert shown in FIGS. **7** and **11**.

FIG. **13** illustrates an isometric view of a heat sink as shown in FIG. **7**.

FIG. **13**A shows a magnified view of a portion of the heat sink shown in FIG. **13**.

FIG. **14** illustrates an isometric view of another embodiment of a heat sink shown in FIG. **7**.

FIG. **14**A shows a magnified view of a portion of the heat sink shown in FIG. **14**.

FIG. **15** illustrates a typical cross-sectional view of a heat sink as shown in FIG. **7**, e.g., as taken along Section **15-15** in FIG. **13** or in FIG. **14**.



FIG. **16** illustrates an example of beveled fins.

FIG. **17** illustrates an example of blunt fins.

FIG. **18**A illustrates a cross-sectional view of a heat sink having a v-shaped, transverse groove in its fins as taken along section line **18-18** in FIG. **14**.

FIG. **18**B illustrates a cross-sectional view of a heat sink having a generally parabolic, transverse groove in its fins as taken along section line **18-18** in FIG. **14**.

FIG. **19** illustrates a cross-sectional view of a heat sink as shown in FIG. **18**A with the manifold insert shown in FIG. **12** overlying the fins of the heat sink.

FIG. **19**A illustrates a cross-sectional view of a heat sink as shown in FIG. **18**A having the manifold insert shown in FIG. **12** overlying the fins of the heat sink.

FIG. **19**B illustrates another cross-sectional view of a heat sink defining a transverse groove and having the manifold insert shown in FIG. **12** overlying the fins.

## DETAILED DESCRIPTION

The following describes various innovative principles related to heat exchange systems by way of reference to specific examples. However, one or more of the disclosed principles can be incorporated in various system configurations to achieve any of a variety of corresponding system characteristics. The detailed description set forth below in connection with the appended drawings is intended as a description of various embodiments and is not intended to represent the only embodiments contemplated by the inventor. The detailed description includes specific details for the purpose of providing a comprehensive understanding of the principles disclosed herein. However, it will be apparent to those skilled in the art after reviewing this disclosure that one or more of the claimed inventions may be practiced without one or more of the illustrated details.

Stated differently, systems described in relation to particular configurations, applications, or uses, are merely examples of systems incorporating one or more of the innovative principles disclosed herein and are used to illustrate one or more innovative aspects of the disclosed principles. Thus, heat exchange systems having attributes that are different from those specific examples discussed herein can embody one or more of the innovative principles, and can be used in applications not described herein in detail, for example to transfer heat to or from components in a data center, laser components, light-emitting diodes, chemical reactions, photovoltaic cells, solar collectors, electronic components, power electronics, opto-electronics (e.g., used in switches) and a variety of other industrial, military and consumer devices now known or hereafter developed. Accordingly, such alternative embodiments also fall within the scope of this disclosure.

### Fluid Circuit

The schematic illustration in FIG. **1** shows several functional features common among disclosed fluid-based heat exchanger systems. For example, the fluid circuit **10** has a first heat exchanger **11** configured to absorb heat from a heat source (not shown in FIG. **1**) and a second heat exchanger **12** configured to reject heat from the circuit **10**. As indicated in FIG. **1**, a working fluid, or coolant, can circulate between the heat exchangers **11**, **12** to carry the energy absorbed by the working fluid in the first heat exchanger to the second heat exchanger **12** where energy can be rejected from the fluid. One or both of the heat exchangers **11**, **12** can be a microchannel heat exchanger.

As used herein, "microchannel" means a fluid conduit, or channel, having at least one major dimension (e.g., a channel width) measuring less than about 1 mm, such as, for example, about 0.1 mm, or several tenths of millimeters.

As used herein, "fluidic" means of or pertaining to a fluid (e.g., a gas, a liquid, a mixture of a liquid phase and a gas phase, etc.). Thus, two regions that are "fluidicly coupled" are so coupled to each other as to permit a fluid to flow from one of the regions to the other region in response to a pressure gradient between the regions.

As used herein, the terms "working fluid" and "coolant" are interchangeable. Although many formulations of working fluids are possible, common formulations include distilled water, ethylene glycol, propylene glycol, and mixtures thereof.

As used herein, the terms "heat sink" and "heat exchanger" are interchangeable and mean a device configured to transfer energy to or from a fluid through convection (i.e., a combination of conduction and advection) heat transfer.

Referring again to FIG. **1**, the working fluid typically enters a first manifold **13** (sometimes after passing through an inlet plenum, which is omitted from FIG. **1** for ease of illustration). From the manifold **13**, the fluid can be distributed among a plurality of fluid passages **14** configured to transfer heat from a heat-transfer surface, e.g., a wall in the heat exchanger **11**, to the working fluid. In some embodiments, such as the examples described below, the fluid passages **14** are configured as microchannels and the walls are configured as extended heat-transfer surfaces, or fins.

During operation of the circuit **10**, energy conducts (e.g., diffuses) from the walls of the first heat exchanger into adjacent fluid particles within the passages **14**, and the adjacent fluid particles are swept away from the wall, or advected, carrying the energy absorbed from the walls. The swept-away particles are replaced by other, usually cooler fluid particles, which more readily absorb energy from the walls (e.g., by virtue of their usually lower temperature). Such a combination of conduction and advection (i.e., convection) provides an efficient approach for cooling devices having a relatively high heat flux, such as, for example, electronic devices.

After passing through the plurality of passages **14** in the first heat exchanger **11**, the heated working fluid collects in an exhaust manifold **15** and passes to the second heat exchanger **12**, carrying with it the energy absorbed from the first heat exchanger **11**. As the heated fluid passes through the second heat exchanger **12**, energy is rejected from the fluid (e.g., to another working fluid, such as, for example, the air or a building's water supply) through convection processes similar to those described above. From the second heat exchanger, the cooled working fluid passes through a pump **16** and back to the first heat exchanger **11**.

The dashed box in FIG. **1** indicates that several functional components of the circuit **10** can be integrated into a single subassembly. As an example, the subassembly **20** includes the pump **16**, the manifolds **13**, **15** and the passages **14**, as well as, for example, conduits between the pump and the manifold **13**. An inlet **21** and an outlet **22** operatively couple the subassembly **20** to the second heat exchanger **12**. A working embodiment of such a subassembly **20** is described below in connection with FIG. **7**, et seq.

Each of the innovative features described herein can be incorporated, either singly or in combination, in connection with the first heat exchanger **11**, the second heat exchanger **12**, or both.



Heat Exchanger Example

With reference to FIGS. **2** to **4**, a fluid heat exchanger **100** is shown. Fluid heat exchanger **100** includes a heat spreader plate **102**, an arrangement of fluid microchannels **103** defined between walls **110**, a fluid inlet passage **104**, and a fluid outlet passage **106**. A housing **109** operates with heat spreader plate **102** to form an outer limit of the heat sink and to define fluid flow passages **104**, **106**.

As shown in FIGS. **3** and **4**, in use the heat exchanger **100** is coupled to a heat source **107**, such as an electronic device, including, but not limited to a microchip or an integrated circuit. The heat exchanger may be thermally coupled to the heat source by a thermal interface material disposed therebetween, by coupling directly to the surface of the heat source, or by integrally forming the heat source and at least the heat spreader plate **102** of the fluid heat exchanger. The heat exchanger **100** may take various forms and shapes, but heat spreader plate **102** is formed to accept thermal energy from heat source **107**. Heat spreader plate **102** includes an intended heat generating component contact region **102*b*** positioned in a known location thereon. In the illustrated embodiment, heat spreader plate **102** includes a protrusion at region **102*b*** that controls the positioning of the heat spreader plate relative to the heat source, but such a protrusion need not be included. Heat spreader plate **102** may include a portion of more conductive material to facilitate and control heat transfer, if desired. In any event, heat spreader plate is formed to fit over and thermally communicate with a heat source in a region **102*b***, usually located centrally relative to the edges of the heat spreader plate.

Microchannels **103** are formed to accept and allow passage therethrough of the flow of heat exchanging fluid such that the fluid can move along heat spreader plate **102** and walls **110** and accept and dissipate heat energy from them. In the illustrated embodiment, microchannels **103** are defined by walls **110** that are thermally coupled to the heat spreader plate to accept thermal energy therefrom. For example, heat spreader plate **102** may include an inner facing, upper surface **102*a*** and a plurality of microchannel walls **110** may extend upwardly therefrom, whereby the channel area, defined between upper surface **102*a*** and the microchannel walls **110**, channels or directs fluid to create a fluid flow path. The channel area may be open or filled with thermally conductive porous material such as metal or silicon foam, sintered metal, etc. Thermally conductive, porous materials allow flow through the channels but create a tortuous flow path.

Surface **102*a*** and microchannel walls **110** allow the fluid to undergo exchange of thermal energy from the heat spreader plate to cool the heat source coupled to the heat spreader plate. The upper surface **102*a*** and walls **110** have a high thermal conductivity to allow heat transfer from the heat source **107** to fluid passing through channels **103**. The surfaces forming channels **103** may be smooth and solid, formed with a porous structure, such as of sintered metal and/or metal or silicon foam or roughened, for example, including troughs and/or crests designed to collect or repel fluid from a particular location or to create selected fluid flow properties. Facing microchannel walls **110** may be configured in a parallel configuration, as shown, or may be formed otherwise, provided fluid can flow between the microchannel walls **110** along a fluid path. It will be apparent to one skilled in the art that the microchannel walls **110** may be alternatively configured in any other appropriate configuration depending on various factors of desired flow, thermal exchange, etc. For instance, grooves may be formed

between sections of microchannel walls **110**. Generally, microchannel walls **110** may desirably have dimensions and properties which seek to reduce or possibly minimize the pressure drop or differential of fluid flowing through the channels **103** defined therebetween.

The microchannel walls **110** may have a width dimension within the range of 20 microns to 1 millimeter and a height dimension within the range of 100 microns to five millimeters, depending on the power of the heat source **107**, desired cooling effect, etc. The microchannel walls **110** may have a length dimension which ranges between 100 microns and several centimeters, depending on the dimensions of, and the heat flux density from, the heat source. In one embodiment, the walls **110** extend the full length (which may be a width) dimension of the heat spreader plate passing fully through region **102***b*. These are exemplary dimensions and, of course, other microchannel wall dimensions are possible. The microchannel walls **110** may be spaced apart by a separation dimension range of 20 microns to 1 millimeter, depending on the power of the heat source **107**, although other separation dimensions are contemplated.

Other microporous channel configurations may be used alternatively to, or together with, microchannels, such as for example, a series of pillars, fins, or undulations, etc. which extend upwards from the heat spreader plate upper surface or tortuous channels as formed by a foam or sintered surface.

Fluid heat exchanger **100** further includes a fluid inlet passage **104**, which in the illustrated embodiment includes a port **111** through the housing opening to a header **112** and thereafter a fluid inlet opening **114** to the microporous fluid channels **103**.

## Fluid Distribution

The port and the header can be formed in various ways and configurations. For example, port **111** may be positioned on top, as shown, side or end regions of the heat exchanger, as desired. Port **111** and header **112** are generally of a larger cross sectional area than opening **114**, so that a mass flow of fluid can be communicated substantially without restriction to opening **114**.

Although only a single fluid inlet opening **114** is shown, there may be one or more fluid inlet openings providing communication from the header to the fluid microchannels **103**.

Fluid inlet opening **114** may open to microchannels **103** opposite the heat spreader plate such that fluid passing through the opening may pass between walls **110** toward surface **102***a*, before being diverted along the axial length of the channels, which extend parallel to axis x. Since most installations will position the heat spreader plate as the lowermost, as determined by gravity, component of heat exchanger **100**, the fluid inlet openings **114** can generally be described as being positioned above the microchannels **103** such that fluid may flow through opening **114** down into the channels in a direction orthogonal relative to the plane of surface **102***a* and towards surface **102***a* and then change direction to pass along the lengths of channels **103** substantially parallel to surface **102***a* and axis x. Such direction change is driven by impingement of fluid against surface **102***a*.

Fluid inlet opening **114** may be positioned adjacent to the known intended heat generating component contact region **102***b* since this region of the heat spreader plate may be exposed to greater inputs of thermal energy than other regions on plate **102**. Positioning the fluid inlet opening adjacent region **102***b* seeks to introduce fresh heat exchanging fluid first and directly to the hottest region of the heat exchanger. The position, arrangement and/or dimensions of opening **114** may be determined with consideration of the position of region **102***b* such that opening **114** may be placed adjacent, for example orthogonally opposite to, or according to the usual mounting configuration above, the intended heat generating component contact region **102***b* on the heat plate. The delivery of fresh fluid first to the region that is in direct communication with the heat generating component to be cooled seeks to create a uniform temperature at the contact region as well as areas in the heat spreader plate away from the contact region.

In the illustrated embodiment, opening **114** is positioned to have its geometric center aligned over the center, for example the geometric center, of region **102***b*. It is noted that it may facilitate construction and installation by intending, and possibly forming, the heat sink spreader plate to be installed with the heat generating component positioned on the plate substantially centrally, with respect to the plate's perimeter edges, and then opening **114** may be positioned also with its geometric center substantially centrally with respect to the perimeter edges of the heat spreader plate. In this way, the geometric center points of each of opening **114**, the heat spreader plate and the heat generating component may all be substantially aligned, as at C.

Opening **114** may extend over any channel **103** through which it is desired that heat exchange fluid flows. Openings **114** may take various forms including, for example, various shapes, various widths, straight or curved edges (in plane or in section) to provide fluid flow features, open area, etc., as desired.

Heat exchanger **100** further includes a fluid outlet passage **106**, which in the illustrated embodiment includes one or more fluid outlet openings **124** from the microporous fluid channels **103**, a header **126** and an outlet port **128** opening from the housing. Although two fluid outlet openings **124** are shown, there may be one or more fluid outlet openings providing communication to the header from the fluid channels **103**.

The port and the header can be formed in various ways and configurations. For example, port **128** may be positioned on top, as shown, side or end regions of the heat exchanger, as desired.

Fluid outlet openings **124** may be positioned at the end of microchannels **103**. Alternately or in addition, as shown, fluid outlet openings **124** may create an opening opposite heat spreader plate **102** such that fluid passing through the channels pass axially along the length of the channels between walls **110** and then changes direction to pass away from surface **102***a* out from between the walls **110** to exit through openings **124**. Since most installations will position the heat spreader plate as the lowermost, as determined by gravity, component of heat exchanger **100**, the fluid outlet openings **124** will generally be positioned above the microchannels **103** such that fluid may flow from the channels upwardly through openings **124**.

Fluid outlet openings **124** may be spaced from fluid inlet openings **114** so that fluid is forced to pass through at least a portion of the length of channels **103** where heat exchange occurs before exiting the microchannels. Generally, fluid outlet openings **124** may be spaced from the known intended heat generating component contact region **102***b*.

In the illustrated embodiment, where heat exchanger **100** is intended to be mounted with heat source **107** generally centrally positioned relative to the perimeter edges of heat

spreader plate **102**, and thereby the ends **103***a* of channels, openings **124** may be positioned at or adjacent channel ends **103***a*.

At least one opening **124** extends over any channel **103** through which it is desired that heat exchange fluid flows. Openings **124** may take various forms including, for example, various shapes, various widths, straight or curved edges (in plane or in section) to provide fluid flow features, open area, etc. as desired.

Fluid inlet opening **114** may open away from the ends of the microchannels, for example along a length of a microchannel between its ends. In this way, fluid is introduced to a middle region of a continuous channel **103** rather than fluid being introduced to one end of a channel and allowing it to flow the entire length of the channel. In the illustrated embodiment, heat exchanger **100** is intended to be mounted with heat source **107** generally centrally positioned relative to the perimeter edges of heat spreader plate **102**. As such, in the illustrated embodiment, opening **114** is positioned generally centrally relative to the edges of the heat plate **102**. Since the channels, in the illustrated embodiment extend substantially continuously along the length of the heat plate between opposing side perimeter edges thereof, opening **114** opens generally centrally between ends **103***a* of each channel. For example, opening **114** may be positioned in the middle 50% of the heat exchanger or possibly the middle 20% of the heat exchanger. The delivery of fresh fluid to the central region where the heat generating component is in direct communication with the heat spreader plate, first before passing through the remaining lengths of channels seeks to create a uniform temperature at region **102***b* as well as areas in the heat spreader plate adjacent to the intended mounting position. The introduction of fluid to a region along a middle region of the microchannels after which the flow splits into two sub flows to pass outwardly from the inlet towards a pair of outlets, each of which is positioned at the ends of the channels reduces the pressure drop of fluid passing along the channels over that pressure drop that would be created if the fluid passed along the entire length of each channel. Splitting the fluid flow to allow only approximately one half of the mass inlet flow to pass along any particular region of the microchannels creates less back pressure and less flow resistance, allows faster fluid flow through the channels and lessens the pump force required to move the fluid through the heat exchanger.

In use, heat spreader plate **102** is positioned in thermal communication with heat source **107** at region **102***b*. Heat generated by heat source **107** is conducted up through heat spreader plate **102** to surface **102***a* and walls **110**. Heat exchanging fluid, as shown by arrows F, enters the fluid heat exchanger through port **111**, passes into the header **112** and through opening **114**. The heat exchanging fluid then passes down between walls **110** into channels **103**, where the fluid accepts thermal energy from the walls **110** and surface **102***a*. The heat exchanging fluid, after passing down into the channels, then impinges against surface **102***a* to be diverted toward ends **103***a* of the channels toward outlet openings **124**. In so doing, in the illustrated embodiment, the fluid is generally split into two subflows moving away from each other and away from inlet **114** toward openings **124** at the ends of the microchannels. Fluid passing through channels becomes heated, especially when passing over the region in direct contact with the heat source, such as, in the illustrated embodiment, the central region of the heat spreader plate. Heated fluid passes out of openings **124**, into header and thereafter through port **128**. The heated fluid will circulate



through a heat sink where its thermal energy is unloaded before circulating back to port **111**.

The individual and relative positioning and sizing of openings **114** and **124** may allow fluid to circulate through the heat exchanging channels **103** while reducing the pressure drop generated in fluid passing through heat exchanger **100**, when compared to other positionings and sizings. In the illustrated embodiment, for example, the central region **124***a* of outlet openings **124** are scalloped to offer an enlarged outlet region from the centrally located channels, relative to those on the edges. This shaping provides that the outlet openings from some centrally positioned channels **103**, relative to the sides of the heat exchanger, are larger than the outlet openings from other channels closer to the edges. This provides that fluid flowing through the more centrally located channels encounters less resistance to flow therethrough, again facilitating flow past the central mounting region **102***b* on heat spreader plate **102**.

A seal **130** separates fluid inlet passage **104** from fluid outlet passage **106** so that fluid must pass through the microporous channels **103** past heat spreader plate surface **102***a*.

## Methods of Manufacture

With reference to FIGS. **5** and **6**, a useful method for manufacturing a fluid heat exchanger is described. A heat spreader plate **202** may be provided which has heat conductive properties through its thickness at least about a central region thereof.

Microchannels may be formed on the surface of the heat spreader plate, as by adding walls or forming walls by building up or removing materials from the surface of the heat plate. In one embodiment, skiving is used to form walls **210**.

A plate **240** may be installed over the walls **210** to close off the channels across the upper limits of walls **210**. Plate **240** has portions removed to create inlet and outlet openings **214** and **224**, respectively, in the final heat exchanger. Tabs **242** may be used to assist with the positioning and installation of plate **240**, wherein tabs **242** are bent down over the two outermost walls.

Seal **230** may be installed as a portion of plate **240** or separately.

After plate **240** and seal **230** are positioned, a top cap **244** can be installed over the assembly. Top cap **244** can include side walls that extend down to a position adjacent heat spreader plate. The parts may be connected during assembly thereof or afterward by overall fusing techniques. In so doing, the parts are connected so that short circuiting from inlet passage to outlet passage is substantially avoided, setting up the fluid circuit as described herein above wherein the fluid flows from opening **214** to openings **224** through the channels defined between walls **210**.

## System Integration

Referring now to FIG. **7**, a working example of an integrated subassembly **20** (FIG. **1**) is described. The illustrated subassembly **300** comprises a pump **310** (e.g., **312** and **313**, exclusive of retention mechanism **302**) and a heat exchanger **320**, as well as housing **330** with integrated fluid conduits extending therebetween. The subassembly **300** is but one example of an approach for integrating several elements of the fluid circuit **10** shown in FIG. **1** (e.g., the pump **16** and the first heat exchanger **11**, including the inlet manifold **13**, the fluid passages **14**, the exhaust manifold **15**)

into a single element while retaining the several elements' respective functions. The illustrated housing **330** is configured to convey a working fluid from an inlet port **331** to a pump volute **311**, from the pump volute to an inlet **321** (FIG. **11**) to the heat exchanger **320**, and from an outlet **322** (FIG. **11**) of the heat exchanger to an outlet port **332**.

The pump impeller **312** can be received in the pump volute **311**. The impeller can be driven in rotation by an electric motor **313** in a conventional manner. A cap **301** can overlie the motor **313** and fasten to the housing **330** to provide the subassembly **300** with a finished appearance suitable for use with, for example, consumer electronics.

The side **333** of the housing **330** positioned opposite the pump volute **311** can receive an insert **334** and the heat exchanger **320**. A seal (e.g., an O-ring) **323** can be positioned between the housing **330** and the heat exchanger **320** to reduce and/or eliminate leakage of the working fluid from the interface between the heat exchanger **320** and the housing **330**.

The heat exchanger **320** defines a lower-most face of the assembly **300**, as well as a surface configured to thermally couple to an integrated circuit (IC) package (not shown). A retention mechanism **302** can mechanically couple the assembly to a substrate, such as a printed circuit board to which the IC package is assembled.

As with the subassembly **20** shown in FIG. **1**, a fluid conduit, or other fluid coupler, can fluidicly couple an outlet port of a remotely positioned heat exchanger to the inlet port **331** of the housing **330**. As well, a fluid conduit, or other fluid coupler, can fluidicly couple the outlet port **332** of the housing **330** to an inlet port of the remotely positioned heat exchanger. In a cooling application, the respective fluid conduits convey relatively higher-temperature fluid from the outlet port **332** to the remote heat exchanger and relatively lower-temperature fluid from the remote heat exchanger to the inlet port **331**.

## Integrated Housing

An embodiment of a unitary housing **330** is now described by way of reference to FIGS. **7**, **8**, **9**, **10** and **11**. The illustrated housing **330** has a first side **340**, a second side **333** positioned opposite the first side, and a substantially continuous perimeter wall **348** extending between the first side and the second side. A floor, or lower wall, **341** (FIG. **9**) generally separates the first side from the second side. The opposed first side **340** and second side **333** define respective recessed features that, when combined with corresponding components, define integrated fluid conduits and chambers operable to convey a working fluid within a small form factor (e.g., within a volume having a maximum vertical dimension of less than about 1.5 inches, such as, for example, between about 0.75 inches and about 1.4 inches).

For example, the housing has an inlet port **331**, a pump volute **311**, an inlet plenum **335** (FIG. **10**), an inlet manifold portion **336** corresponding to the inlet plenum, an exhaust manifold portion **337**, an exhaust (or outlet) plenum **338** corresponding to the exhaust manifold portion, and an outlet port **332** fluidicly coupled with each other.

FIGS. **8** and **9** show that the perimeter wall can define a recessed inlet port **331**. The first side **340** of the housing **330** defines a substantially cylindrically-shaped recess forming the pump volute **311**, and a floor of the recessed volute **311** is defined by a substantially circular lower wall **341**. An aperture **342** in the lower wall forms an inlet to the pump volute **311** from the inlet port, with an inlet passage **343**



extending between the inlet port **331** and the inlet **342** to the pump volute **311**, fluidicly coupling the pump volute and the inlet port to each other.

The opposite (e.g., a second) side **333** of the housing **330** defines a second recessed region **350** defining the inlet (e.g., first) plenum **335** and the inlet manifold region **336**. An opening **344** extends through a common wall **345** separating the inlet plenum **335** from the pump volute **311** (not shown in FIG. **10**), fluidicly coupling the pump volute and the first plenum with each other. In some embodiments, the opening **344** extends generally tangentially of the cylindrically-shaped pump volute **311**.

A charge port **349** can extend through the perimeter wall **348** and into the inlet plenum **335**, allowing an assembled system to be charged with a working fluid after assembly is complete. After charging, a plug (not shown) can be inserted into the charge port **349** to seal it.

As shown in FIG. **10**, a depth of the inlet manifold **336** can taper from a relatively deeper region adjacent the inlet plenum **335** to a relatively shallower region spaced from the inlet plenum. As shown in FIG. **11** and described more fully below, a manifold insert **334** can be positioned adjacent, e.g., "overlie", as shown in FIG. **7**, the sloped recess of the manifold region **336**, at least partially forming an inlet manifold to the heat sink **320** and having a tapering cross-sectional area along a flow direction. The tapered manifold can distribute a substantially even mass-flow rate of working fluid among a plurality of channels in the heat sink **320**.

The second side **333** of the housing **330** can define a third recessed region **351** (FIG. **10**) defining respective portions of an exhaust manifold **337** (FIG. **11**). As described more fully below, the third recessed region **351** can overlie a portion of the heat exchanger **320** and thereby receive a discharged working fluid from the microchannels.

A fourth recessed region **352** (FIG. **10**) can define, at least in part, an outlet plenum **338**. The third recess **351** and the fourth recess **352** can be fluidicly coupled to each other and separated by a wall **346** from the second recessed region **350**. An opening **347** (FIG. **9**) can extend between the outlet plenum **338** and the outlet port **332**.

A manifold housing, or integrated housing, as described above can have a unitary construction formed using, for example, an injection molding technique, a machining technique, or other suitable process now known or hereafter developed. Also, any suitable material can be used in the construction of the housing, provided that the material is compatible with other components of the subassembly **300** and the working fluid. For example, common materials from which an injection-molded housing can be formed include polyphenylene sulfide (commonly referred to as "PPS"), polytetrafluoroethylene (commonly referred to as "PTFE" or the trade name TEFLON by the DuPont Company), and acrylonitrile butadiene styrene (commonly referred to as "ABS").

Although the housing described above has a unitary construction, other embodiments of the housing **330** can comprise an assembly of subcomponents. Nonetheless, a unitary construction typically has fewer separable couplings from which a working fluid can leak.

## Manifold Insert

As noted above and shown in FIGS. **7** and **11**, an insert **334** can be positioned between the heat exchanger **320** and the housing **330**. Additionally, the insert **334** can have a contour generally corresponding to the configuration of one or more of the recessed regions **350**, **351**, **352** in the second

side **333** of the housing **330**. When the insert **334** is mated with the housing **330**, the recessed regions **350**, **351** and **352**, in combination with the contoured insert **334**, can define several conduits, or fluid couplers, suitable for conveying a working fluid so as to fluidicly couple the heat exchanger **320** with the pump volute **311** and the outlet port **332**.

For example, the insert **334** can define an opening extending through the body **360** and generally overlying the tapered manifold portion **336** defined by the housing **330**. The opening can include a recessed region **365** and an aperture **361**. The recessed region **365** and the tapered recess **336** in the housing together define a chamber of the inlet manifold. As described below, the manifold can distribute working fluid among the several microchannels within the heat sink.

The body **360** of the insert **334** can matingly engage with one or more features of the housing **330**. For example, the body **360** can define a plurality of spaced apart members **362***a, b, c, d* and a trough-shaped recess **363** extending transversely relative to the aperture **361**. The trough-shaped recess **363** can extend between the members **362***a, c* and between the members **362***b, d*. When the insert **334** is assembled with the housing **330**, the members **362***a, b, c, d* are positioned in corresponding portions of the second recessed region **351**, and a corresponding ridge **339** (FIG. **10**) is positioned within the trough-shaped recess **363**. By straddling features defined by the housing, the insert is configured to align the aperture **361** with the tapered manifold region **336** in a generally repeatable fashion.

The insert body **360** also defines a contoured tab **364** configured to overly the recessed inlet plenum **335**. In addition, a shoulder **366** within the second recessed region **365** of the insert urges against the wall **346** (FIG. **10**), providing a seal separating the inlet manifold from the exhaust manifold and outlet plenum.

In a working embodiment, the recessed region **365** (FIG. **19**) is tapered, having at least one cross-sectional dimension that diminishes with increasing depth of the recess. As explained more fully below, the recess **365** and the aperture **361** in the insert can generally overlie a groove **325** (FIG. **19**) in the heat sink fins. In some instances, a slope of a wall defining the tapered recess **365** adjacent the aperture **361** can be matched to (e.g., can correspond to, or, alternatively, be the same as) a slope of the recessed groove **325** adjacent a distal end of the heat sink fins, providing a relatively smooth and continuous flow transition.

The insert can have one or more (e.g., a pair) of generally conformable, flat surfaces **367** laterally flanking the aperture **361** (FIG. **11**). As shown in FIG. **19**, the surfaces **367** can generally overlie respective portions of the heat exchanger **320** (e.g., the distal ends **401** of heat sink fins **400** (FIGS. **16** and **17**)), defining an upper flow boundary of the microchannels extending between adjacent fins, similar to the plate **240** shown in FIGS. **5** and **6**. The conformable surfaces **367** can urge against the respective distal ends, and conform to variations in height among the plurality of fins, and within a given fin (e.g., a fin having a non-linear longitudinal contour resulting from variations in fin height $h_2$ (FIGS. **18**A and **18**B)). The conformable surfaces **367** can reduce or eliminate the need for secondary machining operations used to make the respective distal ends of the fins generally coplanar and compatible with, for example, a rigid plate. As well, conformable surfaces **367** urging against the distal ends **401** of the fins **400** (**400'**) can form a seal with the fins and prevent a working fluid from bypassing the channels defined between adjacent fins.



The insert body **360** can be formed using, for example, an injection molding technique, a machining technique, or other suitable process now known or hereafter developed. In a working embodiment, the body **360** is formed of a compliant polymeric material that generally conforms to and seals against adjacent surfaces. Any suitable material can be used to form the insert body **360**, provided that the selected material is compatible with other components of the subassembly **300** and the selected working fluid. For example, common materials from which the insert body can be formed include silicone or any other suitably compliant material.

## Flow Distribution

Flow of a working fluid through the integrated assembly **300** is now described. From a remotely positioned heat exchanger (not shown), a working fluid passes into the inlet port **331** and into the channel **343** extending between the inlet port and the inlet **342** to the pump volute **311**. A floor **341** of the pump volute defines a wall separating the channel **343** from the pump volute. From the channel **343**, the working fluid passes through the aperture **342** and into the volute **311**. An impeller **312** positioned in the pump volute **311** rotates and increases a pressure head in the working fluid before the fluid passes from the pump volute through the opening **344** and into the inlet plenum **335**.

As indicated by the arrows in FIG. **10**, the working fluid can pass from the inlet plenum **335** and into a chamber formed between the second recessed region **365** in the insert **334** and the inlet manifold portion **336** of the housing. From the chamber, the working fluid passes through the aperture **361**.

As described above in connection with FIGS. **2**, **3** and **4**, the heat exchanger shown in FIGS. **7**, **11**, **13** and **14** can comprise a heat transfer region **324** defining a plurality of microchannel passages. The aperture **361** can overlie the heat transfer region **324**, and the flow of working fluid can be distributed among the plurality of microchannel passages in the heat sink. As with the assembly shown in FIGS. **5** and **6**, a flow of working fluid within the microchannel can generally be an impinging flow divided into a first portion and a second portion flowing outwardly from the impingement region in generally opposite directions.

In the illustrated assembly **300** (FIG. **7**), the insert **334** (e.g., the members **362** *a,b,c,d*) partially occupies the third recessed region **351**, leaving a pair of opposed portions of the region unfilled and defining opposed exhaust manifold portions **337** overlying end regions of the microchannels and flanking the central region adjacent the aperture **361** (FIG. **11**). The outwardly directed flow of coolant can exhaust from the microchannel passages into a respective one of the exhaust manifold portions **337**. From the manifold portions **337**, the working fluid passes into the outlet plenum **338** (FIG. **11**), and through the conduit **347** to the outlet port **332**.

## Additional Heat Exchanger Configurations

Additional heat sink embodiments are described with reference to FIGS. **13**, **13**A, **14**, **14**A, **15**, **16**, **17**, **18**A and **18**B and **19**. As with the heat sink illustrated in FIG. **2** through FIG. **6**, the heat sinks **320**, **320'** shown in FIGS. **13** and **14** define respective heat transfer regions **324**, **324'** having a plurality of juxtaposed fins (e.g., fins **400**) defining a corresponding plurality of microchannels (e.g., microchannels **404**, **404'**) between adjacent fins.

Each of the fins **400**, **400'** extend from a heat spreader, or base, **326**, to a respective distal end **401**, **401'**. Flanking grooves **322**, **322'** (FIGS. **13** and **14**) can extend orthogonally relative to opposed outer ends of the microchannels **404**, **404'**, forming a portion of an exhaust manifold. When incorporated in the assembly **300**, the grooves **322**, **322'** are generally positioned adjacent opposed exhaust manifold portions **337**.

FIG. **15** shows a typical cross-sectional view of the heat sinks **320**, **320'** along section line **15-15** (FIG. **13**) or **15'-15'** (FIG. **14**), respectively. FIGS. **16** and **17** show alternative fin configurations from the circled portion "A" of a typical heat transfer region shown in cross-section in FIG. **15**.

The distal ends of the fins can have a variety of configurations, as indicated in FIGS. **16** and **17**. For example, the blunt distal ends **405'** are shown as being relatively flat and generally coplanar. Alternatively, the distal ends **401** are shown as being beveled, giving each fin **400***a* a comparatively shorter face and a comparatively taller face, with a relatively sharp apex **405** positioned therebetween.

It is believed that the relatively sharp apex **405** formed by the beveled distal ends **401** can improve transition of a flow direction (e.g., a 90-degree bend) from being generally parallel to the base **326** and orthogonal to the fins **400** to a direction being generally orthogonal to the base **326** and generally parallel to the fins. Accordingly, it is surmised that fins **400** having sharp apices **405** formed by beveled distal ends can reduce head losses in the working fluid as it passes from the insert manifold **365** to the microchannels **404** as compared to, for example, fins **400'** having generally blunt distal ends **405'**. It is believed that positioning the relatively taller face of a given fin upstream of the relatively shorter face of the same fin (e.g., placing the sharp apex in an upstream position relative to the respective fin), provides a relatively larger reduction in head loss than if the flow approaches the beveled fin from an opposite direction.

The beveled distal ends **401** can be formed using any suitable technique for beveling thin walls. For example, such bevels can be produced when forming the fins **400** using a skiving technique. Other, e.g, proprietary, techniques can be used to form the bevels. For example, it is believed that the fin-forming technique employed by Wolverine Tube, Inc. can be used to produce microchannel heat sinks having beveled fins. However, it is also believed that the respective distal ends of such "raw" fins may not be coplanar (apart from a recessed region forming a portion of a transverse groove). By incorporating the compliant insert **334**, which can urge against and form a seal with uneven fins, secondary machining operations that would tend to dull the sharp apices **405** can be eliminated, saving costs and improving performance. Maintaining sharp apices **405** and forming a seal with the manifold insert can reduce head losses in the coolant, while still reducing or eliminating leakage between adjacent microchannels **404** that might otherwise occur through gaps that would otherwise be formed between the "raw" fins and, e.g., a generally planar, rigid plate.

As shown in FIG. **14**, a transverse groove **325** can extend transversely relative to the fins **400**. As noted above, the aperture **361** in the manifold insert **334** can generally overlie the groove **325**, defining a flow transition that hydraulically couples in parallel each of the microchannels **404** to at least one other of the microchannels.

FIG. **19** shows a cross-sectional view of one example of such a flow transition. The recessed region **365** defined by the insert body **360** and the recessed groove **325** together define a substantially larger characteristic length, e.g., hydraulic diameter, than the aperture **361** does alone. For example, the recessed region **365**, the aperture **361** and the groove **325** can together define a flow transition having a hydraulic diameter between about 150% and about 200% larger than the corresponding hydraulic diameter of the aperture **361** alone, which can provide a substantially lower head-loss coefficient for the assembled flow transition.

Increasing the characteristic length scale of the transition from the inlet manifold to the microchannels of the heat sink **320** can reduce pressure losses in a fluid passing through the transition and increase the flow rate of the fluid in correspondence with the pump's performance. The increase in fluid flow rate resulting from a lower head-loss coefficient can improve local heat transfer rates from the fins compared to a configuration in which the aperture **361** overlies an array of uniform height fins. The combination of the tapered recess **365** and the heat sink groove **325** (e.g., in FIG. **19**A) allows the working fluid to penetrate relatively deeper in the microchannels in a region adjacent the aperture **361** than the fluid otherwise would in the absence of the groove (e.g., in the case of an array of uniform height fins shown in FIG. **19**A).

The groove **325** can be formed by defining a respective recess in each of the plurality of fins **400**. The plurality of recessed regions can be so juxtaposed as to define the groove **325**.

In FIGS. **18**A and **18**B, the lowermost extent of each recessed groove **325***a*, **325***b* is spaced a distance $h_1$ from the heat spreader **326**. In other embodiments, the lowermost extent of the recessed groove **325** is substantially coextensive with the heat spreader **326** (i.e., $h_1 \leq 0$). In some embodiments, a ratio of a representative height $h_2$ of the fins to the distance $h_1$ can be between about 10:1 and about 10:7, such as, for example, between about 3:1 and about 2:1.

Although a v-shaped notch is shown in FIG. **18**A, and a generally parabolic recess is shown in FIG. **18**B, other recessed groove configurations are possible. For example, the groove can have a generally hyperbolic cross-sectional shape, or a cross-section with at least one substantially straight edge (e.g., an L-shaped recess, a flattened "V"-shaped grove as shown in FIG. **19**B). As noted above, a slope of the groove **325** adjacent the manifold body can be substantially continuous with a slope of a wall defining the recessed region **365** in the manifold body **360** adjacent the groove, when the integrated assembly **300** is assembled. Such a continuous slope can provide generally lower head losses through the transition than in transitions having a discontinuity in wall slope (e.g., between the recess in the insert and the groove).

## Other Exemplary Embodiments

The examples described above generally concern fluidic heat transfer systems configured to cool one or more electronic components, such as integrated circuits. Nonetheless, other applications for disclosed heat transfer systems are contemplated, together with any attendant changes in configuration of the disclosed apparatus. Incorporating the principles disclosed herein, it is possible to provide a wide variety of systems configured to transfer heat using a fluid circuit. For example, disclosed systems can be used to transfer heat to or from components in a data center, laser components, light-emitting diodes, chemical reactions, photovoltaic cells, solar collectors, and a variety of other industrial, military and consumer devices now known and hereafter developed.

Directions and references (e.g., up, down, top, bottom, left, right, rearward, forward, etc.) may be used to facilitate

discussion of the drawings but are not intended to be limiting. For example, certain terms may be used such as “up,” “down,”, “upper,” “lower,” “horizontal,” “vertical,” “left,” “right,” and the like. Such terms are used, where applicable, to provide some clarity of description when dealing with relative relationships, particularly with respect to the illustrated embodiments. Such terms are not, however, intended to imply absolute relationships, positions, and/or orientations. For example, with respect to an object, an “upper” surface can become a “lower” surface simply by turning the object over. Nevertheless, it is still the same surface and the object remains the same. As used herein, “and/or” means “and” or “or”, as well as “and” and “or.” Moreover, all patent and non-patent literature cited herein is hereby incorporated by references in its entirety for all purposes.

The principles described above in connection with any particular example can be combined with the principles described in connection with any one or more of the other examples. Accordingly, this detailed description shall not be construed in a limiting sense, and following a review of this disclosure, those of ordinary skill in the art will appreciate the wide variety of fluid heat exchange systems that can be devised using the various concepts described herein. Moreover, those of ordinary skill in the art will appreciate that the exemplary embodiments disclosed herein can be adapted to various configurations without departing from the disclosed principles.

The previous description of the disclosed embodiments is provided to enable any person skilled in the art to make or use the disclosed innovations. Various modifications to those embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without departing from the spirit or scope of this disclosure. Thus, the claimed inventions are not intended to be limited to the embodiments shown herein, but are to be accorded the full scope consistent with the language of the claims, wherein reference to an element in the singular, such as by use of the article “a” or “an” is not intended to mean “one and only one” unless specifically so stated, but rather “one or more”. All structural and functional equivalents to the elements of the various embodiments described throughout the disclosure that are know or later come to be known to those of ordinary skill in the art are intended to be encompassed by the elements of the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims. No claim element is to be construed under the provisions of 35 USC 112, sixth paragraph, unless the element is expressly recited using the phrase “means for” or “step for”.

Thus, in view of the many possible embodiments to which the disclosed principles can be applied, it should be recognized that the above-described embodiments are only examples and should not be taken as limiting in scope. I therefore reserve all rights to the subject matter disclosed herein, including the right to claim all that comes within the scope and spirit of the following claims, as well as all aspects of any innovation shown or described herein.

The invention claimed is:

**1**. A heat exchange system comprising:

a housing defining a recessed region and an outlet port fluidicly coupled with the recessed region;

a heat sink having a plurality of juxtaposed fins defining a corresponding plurality of microchannels between adjacent fins;



a manifold body at least partially defining an opening overlying the microchannels,

wherein the manifold body defines a pair of compliant surfaces flanking the opening,

wherein the compliant surfaces urge against the fins, defining a flow boundary of the microchannels,

wherein the opening extends transversely relative to the fins and is configured to distribute a working fluid among the microchannels,

wherein the manifold body partially occupies the recessed region of the housing, leaving a pair of opposed portions of the recessed region unfilled, defining opposed exhaust manifold portions flanking the opening and being configured to receive the working fluid from the microchannels, and

wherein the housing further defines an outlet plenum configured to receive the working fluid from the exhaust manifold portions and to convey the working fluid to the outlet port.

**2**. The heat exchange system according to claim **1**, wherein the housing defines a pump volute and a segment of a flow path, the segment configured to convey the working fluid from the pump volute to the opening at least partially defined by the manifold body, the heat exchange system further comprising an impeller positioned in the pump volute and configured to urge the working fluid along the flow path.

**3**. The heat exchange system according to claim **2**, wherein the pump volute is positioned opposite the recessed region of the housing relative to the housing.

**4**. The heat exchange system according to claim **2**, wherein the housing defines a boundary of the pump volute, and wherein the flow path extends through the boundary of the pump volute.

**5**. The heat exchange system according to claim **2**, wherein the housing defines an inlet port, wherein the flow path extends from the inlet port to the outlet port and is configured to convey the working fluid from the inlet port through the pump volute, the manifold body, the microchannels, the opposed exhaust manifold portions, and the outlet plenum to the outlet port.

**6**. The heat exchange system according to claim **5**, wherein, in each of the microchannels, the flow path bifurcates into a pair of opposed, outwardly directed flow paths, wherein each outwardly directed flow path exhausts from the respective microchannels into a corresponding one of the exhaust manifold portions.

**7**. The heat exchange system according to claim **6**, wherein each pair of bifurcated flow paths recombine in the outlet plenum.

**8**. A heat exchange system according to claim **5**, further comprising a heat exchanger configured to reject heat from the working fluid, wherein the heat exchanger has an inlet fluidicly coupled with the outlet port defined by the housing, wherein the heat exchanger further has an outlet fluidicly coupled with the inlet port defined by the housing.

**9**. The heat-exchange module according to claim **1**, wherein a flow of the working fluid defines a flow path, wherein the flow path is distributed among the plurality of microchannels, and, within each microchannel, the flow path bifurcates into a pair of opposed sub-flow paths directed away from each other.

**10**. The heat-exchange module according to claim **9**, wherein one in each pair of sub-flow paths extends into the first exhaust region and the corresponding other sub-flow path extends into the second exhaust region.

**11**. The heat-exchange module according to claim **9**, wherein each pair of opposed sub-flow paths recombine with each other in the outlet plenum.

**12**. The heat-exchange module according to claim **1**, wherein the compliant surfaces of the manifold body conform to and seal against the fins, inhibiting the working fluid from bypassing the plurality of microchannels.

**13**. A fluid heat exchanger for cooling an electronic device, the heat exchanger comprising:

a plurality of walls defining a corresponding plurality of microchannels, wherein each microchannel extends from a first end to a second end;

a plate overlying the walls; and

a seal, wherein the seal is a portion of the plate;

a fluid inlet passage configured to deliver a heat-exchange fluid through one aperture in the plate to each microchannel at a position between the corresponding first end and the corresponding second end of the respective microchannel;

a fluid outlet passage configured to receive the heat-exchange fluid from the first end and the second end of each microchannel, wherein the fluid outlet passage has a first outlet region positioned adjacent the microchannel first ends and a second outlet region positioned adjacent the microchannel second ends, wherein the seal separates the fluid inlet passage from the fluid outlet passage;

wherein a flow of the heat-exchange fluid through the one aperture in the plate bifurcates into two sub flows within each microchannel, wherein the first outlet region receives one of the two sub flows adjacent the microchannel first ends and the second outlet region receives the other of the two sub flows adjacent the microchannel second ends, wherein the two sub flows recombine in the outlet passage.



**14**. The fluid heat exchanger according to claim **12**, wherein the plurality of microchannels comprises at least two opposed outer microchannels and a centrally located microchannel positioned between the opposed outer microchannels, wherein the first outlet region is smaller adjacent at least one of the outer microchannels relative to adjacent the centrally located microchannel.

**15**. The fluid heat exchanger according to claim **12**, wherein the plurality of microchannels comprises at least two opposed outer microchannels and a centrally located microchannel positioned between the opposed outer microchannels, wherein the first outlet region comprises an outlet opening from each microchannel, wherein the outlet opening from the centrally located microchannel is larger than the outlet opening from at least one of the outer microchannels.

**16**. The fluid heat exchanger according to claim **12**, wherein the plate and the seal comprise a unitary manifold body defining a pair of compliant surfaces flanking the one aperture through which the heat exchange fluid is delivered to each of the microchannels.

**17**. The fluid heat exchanger according to claim **16**, wherein the compliant surfaces urge against the walls, defining a flow boundary of the microchannels.

**18**. The fluid heat exchanger according to claim **16**, further comprising a housing defining a recessed region at least partially occupied by the unitary manifold body.

**19**. The fluid heat exchanger according to claim **18**, wherein the housing defines a pump volute fluidicly coupled with the fluid inlet passage.

**20**. The fluid heat exchanger according to claim **13**, further comprising a housing defining a recessed region at least partially occupied by the unitary manifold body.

**21**. The fluid heat exchanger according to claim **20**, wherein the housing defines a pump volute fluidicly coupled with the fluid inlet passage.

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